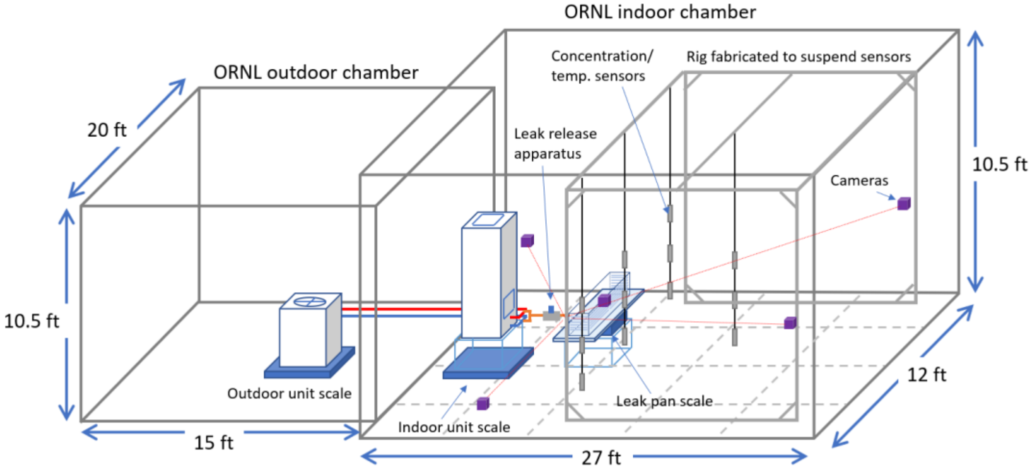
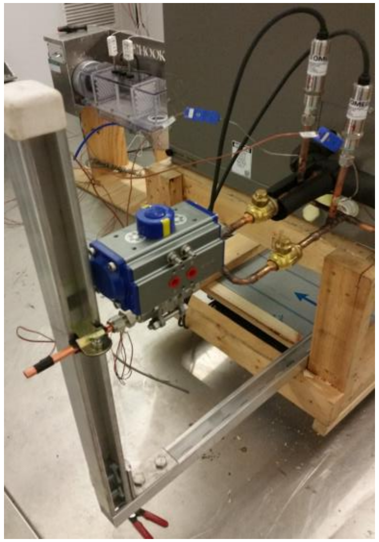
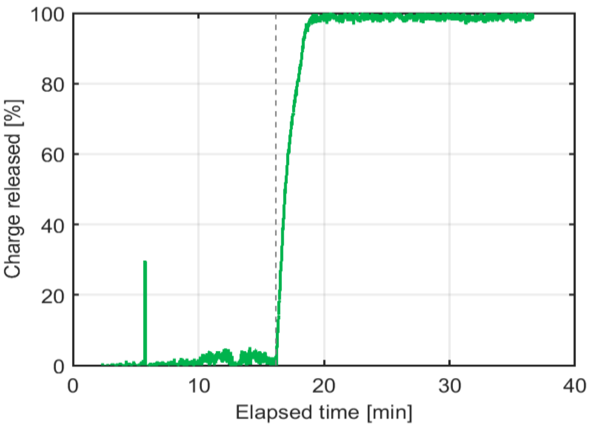
Real-World Refrigerant Leak Assessments







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Project Summary

Timeline:

Start date: 10/01/2017

Planned end date: 09/30/2019

Part of AHRI/ASHRAE/CA/DOE collaboration on flammable refrigerant R&D, initiated 2016

Key Milestones

1. Identify and complete test plans for five initial priority HVAC&R systems, 12/31/2017
2. Complete testing for five initial systems/draft report, 09/30/2018 orig; ***12/31/2018 actual***
3. Identify and complete test plans for two additional HVAC&R systems (including ductwork impacts on refrigerant dispersion in room), 12/31/2018
4. Complete additional systems tests/leak correlations/draft report, 09/30/2019

Key Partner:

Air-Conditioning, Heating, and Refrigeration Technology Institute (AHRTI)

Budget:

Total Project $ through March 2019:

- DOE: $720K
- Cost share: $30K, donated test systems

Total Project $:

- DOE: $850K
- Cost share: $40K, donated test systems

Project Outcome:

Develop lab test data and correlations for actual refrigerant release rates under range of systems, leak locations, leak orifice sizes, and system operating state (on or off)

Provide information to HVAC&R industry to help enable wider use of flammable but environmentally friendly refrigerants for different applications with the potential for 90+% reduction in direct, refrigerant-related global warming impact

Team

Within DOE, ORNL is the center of excellence in commercial and residential building equipment R&D along with supporting analysis tool development.

Team members for this project include:

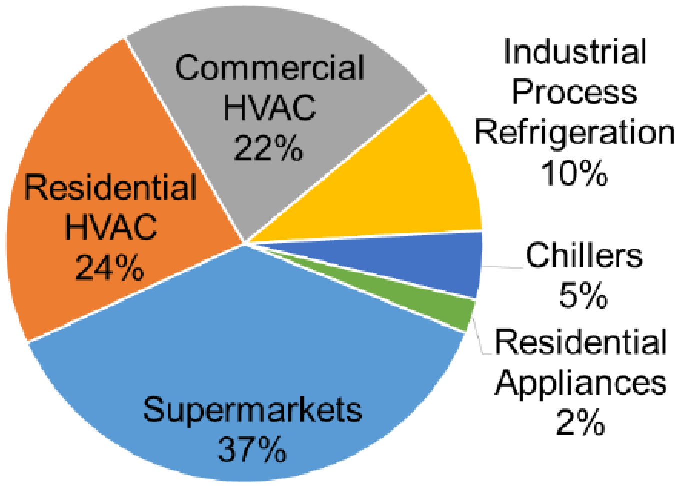
- **Dr. Ahmad Abu-Heiba**—Controlled lab leak testing, stakeholder interaction, lead leak rate correlation development
- **Dr. Viral Patel**—Controlled lab leak testing, stakeholder interaction, lead project reports coordination
- **Van Baxter**—Project manager/PI, overall project direction

Challenge

Problem Definition:

- Pressure mounting to reduce use of high global warming potential (GWP) refrigerants
  - Montréal Protocol limits use of high GWP hydrofluorocarbon (HFC) refrigerants
  - US total HFC use in 2013 was ~250M metric tons CO_{2e}; new equipment and service ~50/50 split
  - Most low-GWP alternatives are flammable
    - Flammable refrigerant charge limits in current safety standards based on fixed 4 min release
- Input from literature review and workshop of companion charge limits estimation project
  - Leak rates depend on equipment type and operating state, location, leak orifice size, etc.

Percentage of Annual Refrigerant Consumption for HVAC&R Equipment Service (GWP Equivalent)



Source: Figure 1-2 in DOE/EE-1270, "R&D Opportunities for Joining Technologies in HVAC&R," Goetzler et al., 2015.

Key need:

- Provide industry and safety standards developers with data on refrigerant leak times for range of equipment, orifice sizes, leak locations (high-side or low-side), and operating state (on or off); help facilitate wider use of flammable lower GWP alternatives
- Project goals
  - Perform controlled lab testing to measure leak rates under typical operating conditions
  - Develop correlation(s) of release rates vs. range of relevant parameters

Approach

- **Industry engagement throughout project**
  - Conduct regular review meetings with AHRTI project monitoring subcommittee (PMS)
    - Helped to quickly prioritize initial HVAC/R systems and test matrix for initial phase (year 1)
    - Provided test units for leak testing and feedback/advice on test and instrumentation setup and results interpretation
    - Assisted in communicating results to standards developers
- **Perform lab tests to measure leak rates for selected systems**
  - Phase 1, completed: split res. AC, packaged terminal AC, rooftop AC, self-contained refrigerated display case, cold storage room unit cooler
  - Phase 2, planned: split res. HP (with duct work), multisplit variant refrigerant flow (VRF) AC
- **Develop correlation(s) of leak rate vs. test parameters**

Impact

Impact of Project:

- **National energy market for HVAC&R equipment using high GWP refrigerants amounts to ~7 Quad/year in 2030**
  - ~2.4 Quad/year for residential space heating and AC alone (~$30B/year @ 2018 avg elec. price)
- **Success in achieving goals would provide the industry with hard data on leak rates and other characteristics to help justify/facilitate revised charge limits**
  - Success will enable wider use of efficient and environmentally friendly refrigerants with potential 90%+ reduction of direct refrigerant-related greenhouse gas (GHG) emissions
  - System evaluations by AHRI and DOE show potential for 10%+ improvement in energy efficiency with system optimization (~0.24Q/year energy savings if these alternatives replace all R-410A and other legacy refrigerant-based residential heat pump and AC systems)
- **Publications will inform national and international standards and codes developers**

✓ **Project directly supports BTO Emerging Technologies 2016–20 Multi-Year Program Plan**

  ✓ Goal---enable 45% reduction in building energy use intensity (EUI) in 2030 vs. 2010 EUI

  ✓ HVAC/WH/Appliances Strategy 1: Near-Term Technology Improvement

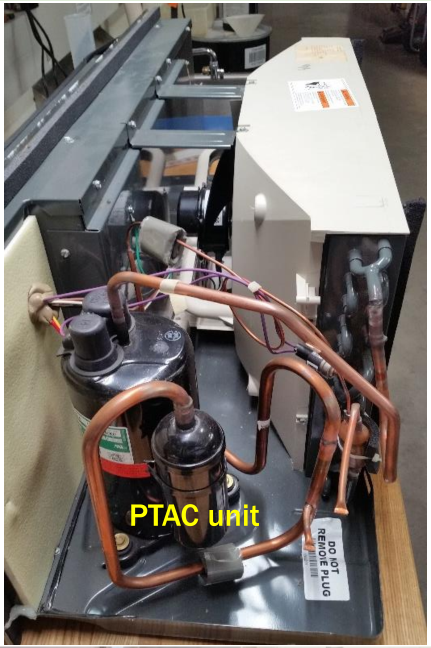
Progress — General Test Requirements

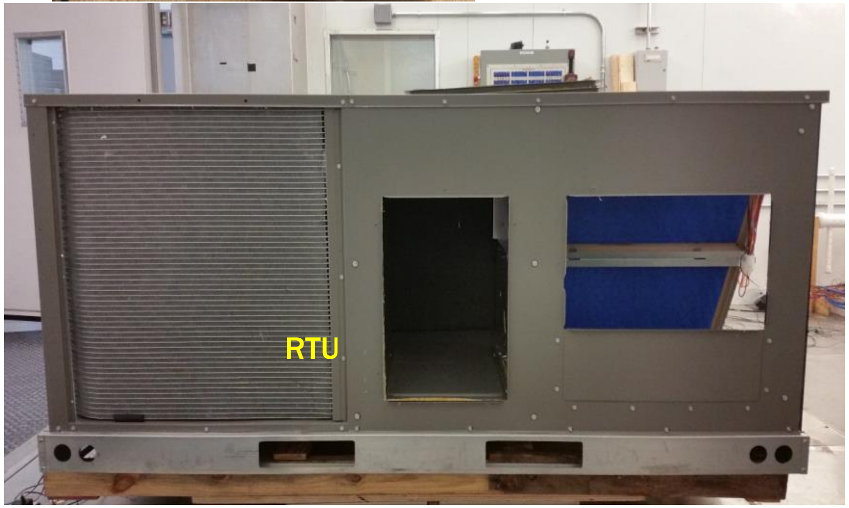
- **Test program to document characteristics of refrigerant leak events in AC and refrigeration equipment (AHRTI project 9012)**
- **Refrigerant leak testing under a controlled environment**
  - Standardized test method with video recording and measurements for temperature, pressure decay, leak flow rate, oil loss
  - Fixed operating ambient temperatures/RH conditions
  - Test parameters listed below
    - R-410A and R-404A used as surrogate for flammables

Application	Refrigerant	Leak rates	Equipment type	Equipment states	Leak locations	Total # of tests
AC	R-410A	2	3	2	2	25
Refrigeration	R-404A	2	2	2	2	16

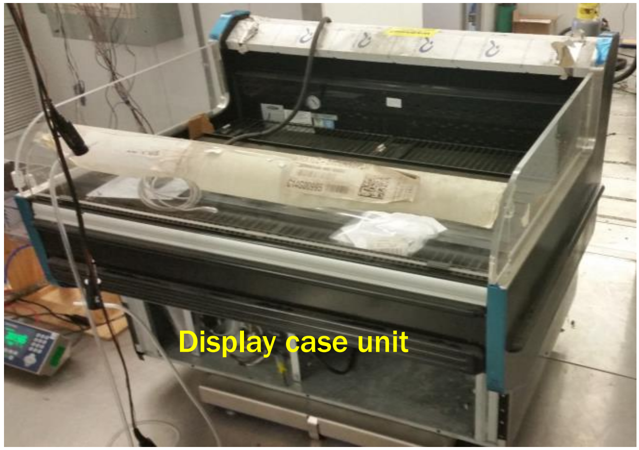
Progress — Test Systems, Phase 1

AC systems



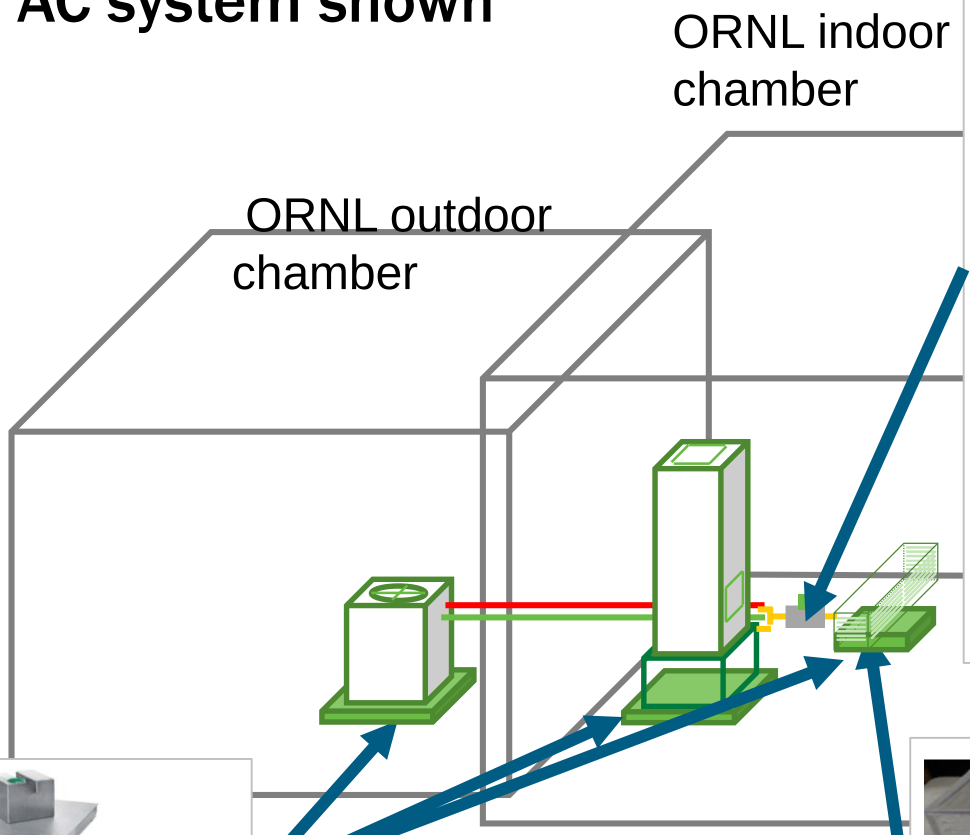


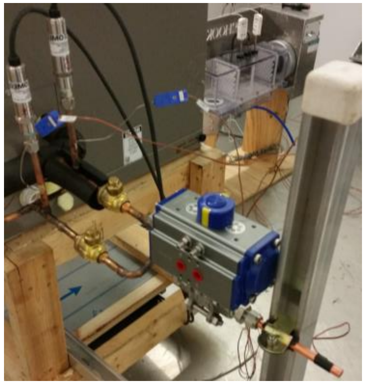
Refrigeration systems



Progress — General Test Setup, Phase 1

Split AC system shown



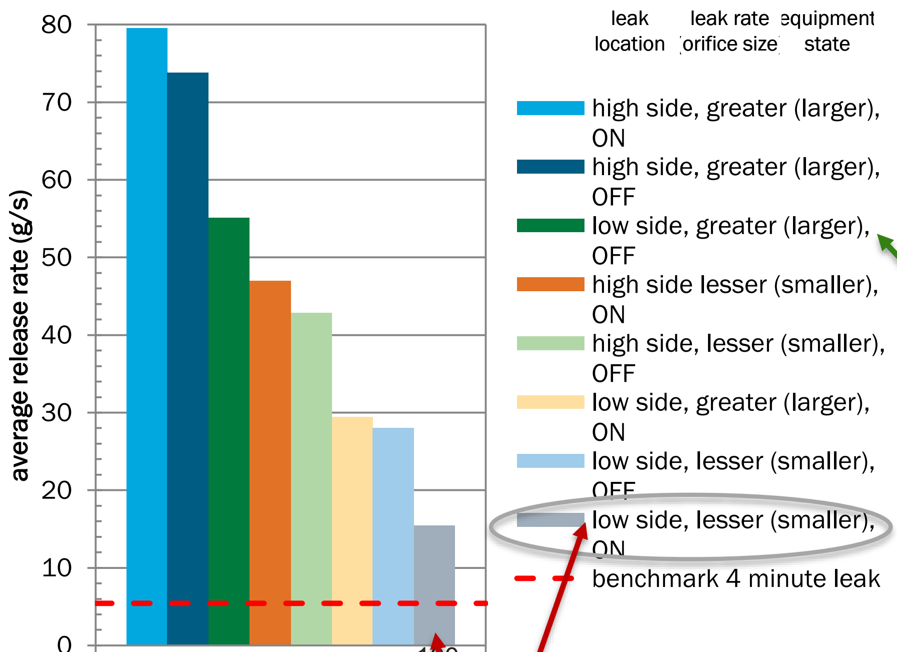


- Automatic ball valve to initiate/terminate refrigerant release events
- High- and low-side refrigerant pressure, 0–500 psia/0–3447 kPa (±0.25 psi/±1.72 kPa)
- High- and low-side refrigerant temperature (±0.5° C)

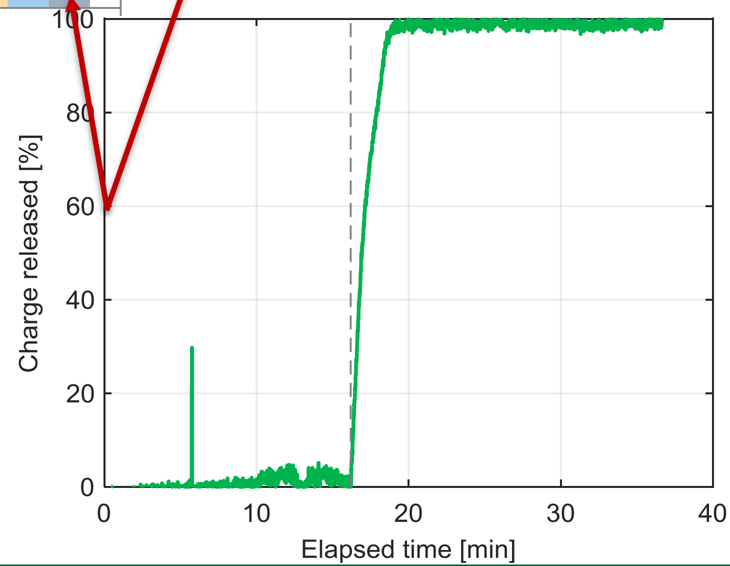
High-precision scales to measure refrigerant & oil loss vs. time

Transparent polycarbonate box in drip pan to capture any oil released with refrigerant

Progress — Phase 1 Summary Leak Results

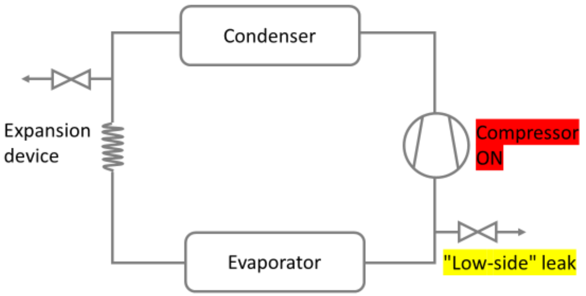


Split AC

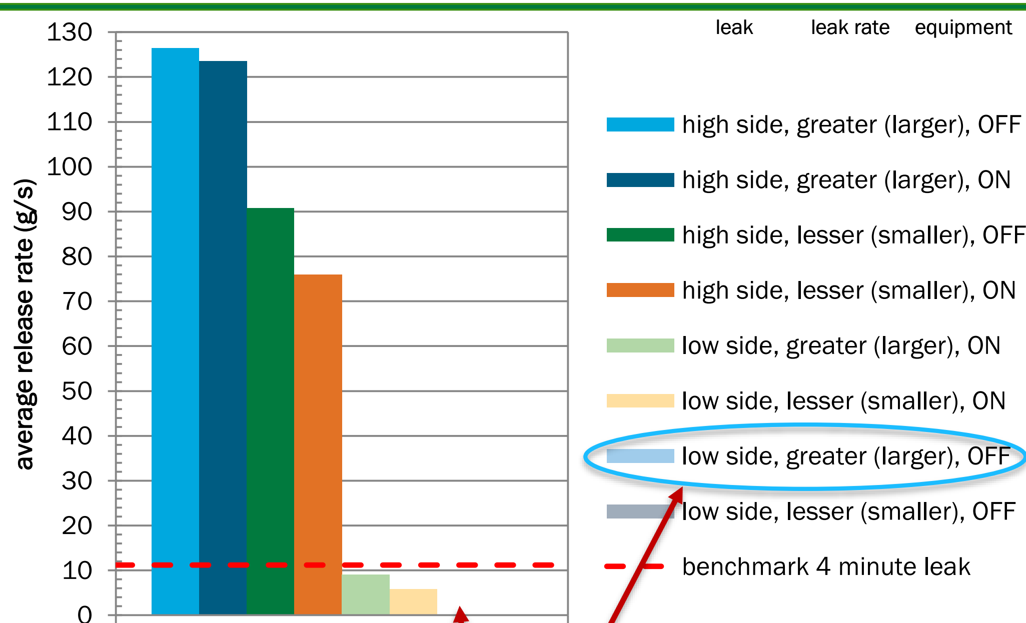


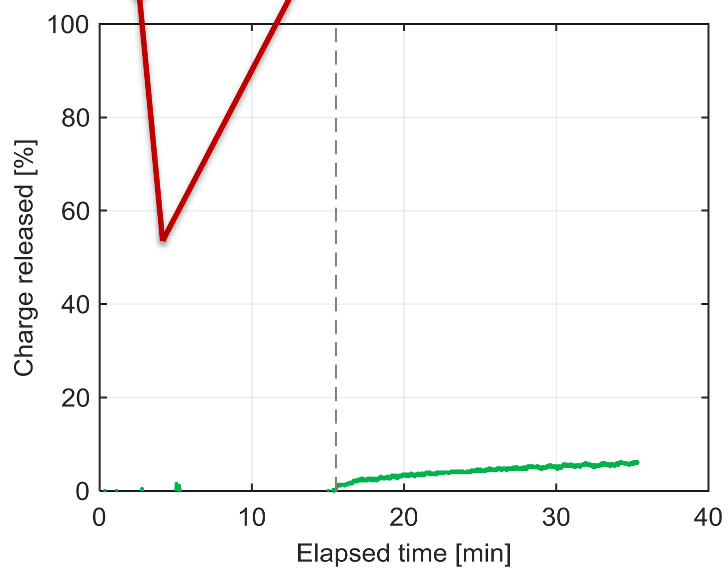
AC systems and display case

- **Two leak rates**
  - "larger orifice" — worst case, liquid line break
  - "smaller orifice" — ~35-40% area of larger orifice
- **Fastest leak: compressor on, high side release, larger orifice**
- **Slowest: compressor on, low side release, smaller orifice**
- **Rates exceeded 4 min release time rate**
- **No significant oil release except for split AC "low side release, larger orifice" test (~0.16 kg)**
- **Feedback from standards developers: interest in obtaining data for 4 min or longer release time leak events (e.g., lesser leak rates)**
  - Closer to release time assumed for original charge limit estimation
  - Revising orifice selection approach for Phase 2



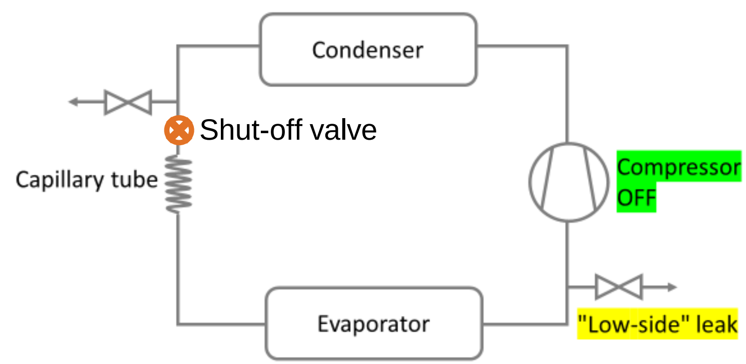
Progress — Phase 1 Summary Leak Results





Unit cooler

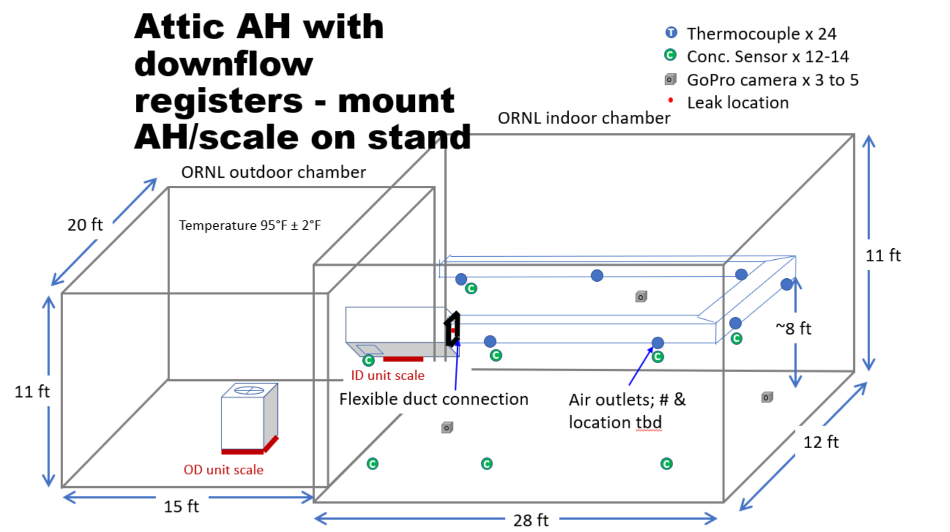
- Included liquid line shut-off valve
- Greatly restricted leak flow for unit off, low side release tests
  - Only ~4-6% of total charge released during 20 min test time

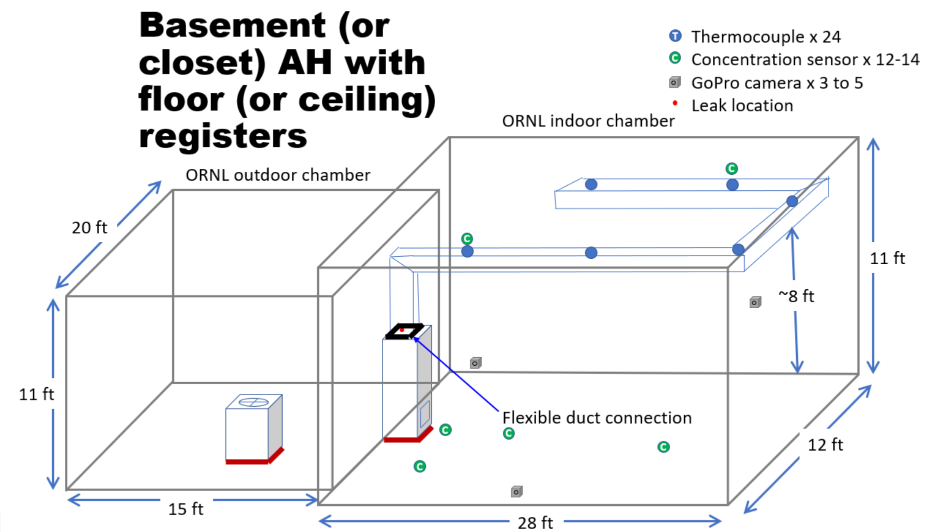


Remaining Project Work — Phase 2 Tests

- **Two additional test systems**
  - Multisplit or VRF AC system; two ID units, 1 OD---8 tests
  - Split heat pump with supply ducts (investigate in-duct refrigerant release impacts on refrigerant dispersal to space)---32 or 64 tests
    - Two different duct layouts
      - Basement or utility closet air handler location
      - Attic AH location
    - Refrigerant concentration sensors at supply/return registers and scattered in room
    - Both heating and AC mode operation (unit on and off)
    - *Maybe* two different charge sizes
- **Leak test approach similar to Phase 1 except;**

will select "larger" orifice to target 4 min release and "smaller" orifice to target 20 or 40 min release

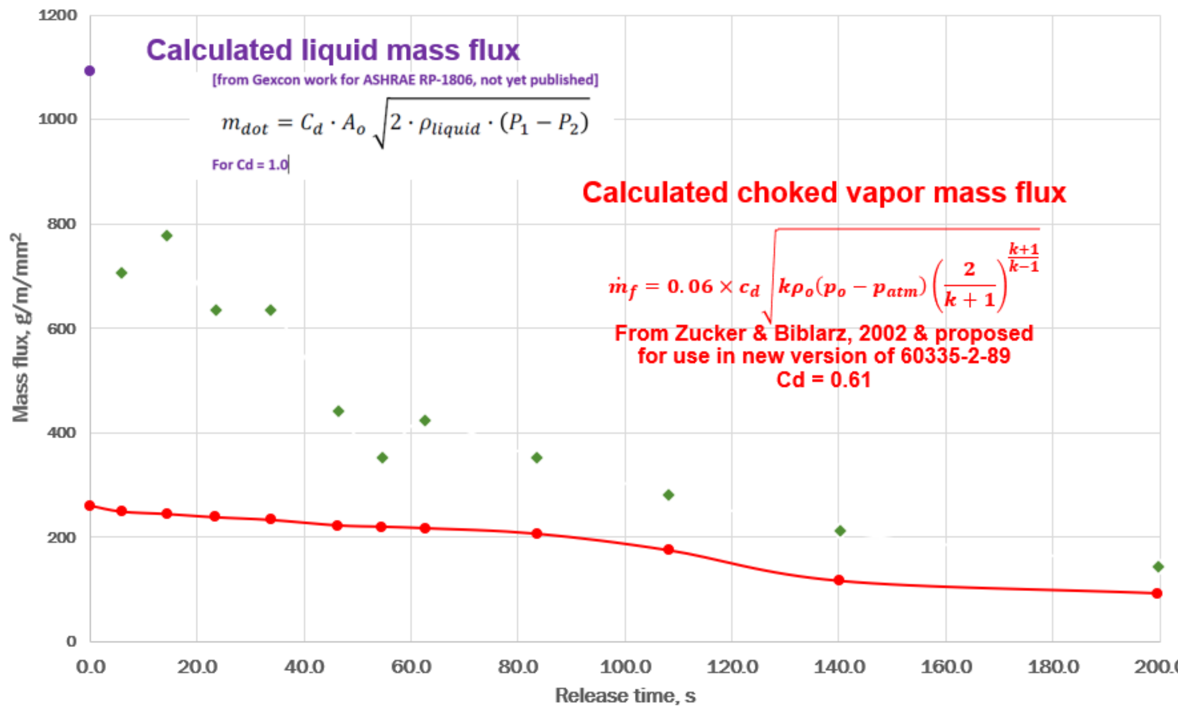


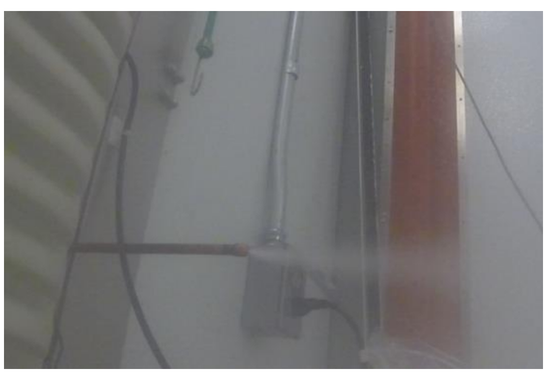


Progress — Correlation Development

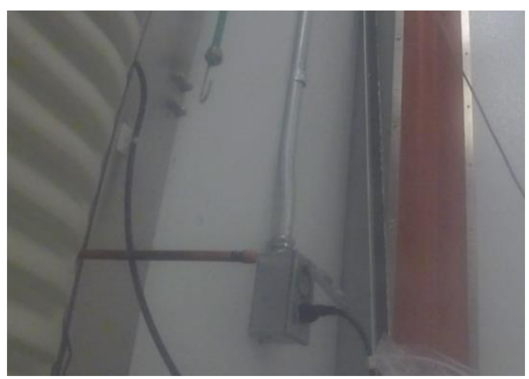
Measured mass flux from PTAC test (diamonds) vs. literature calculations for pure liquid and vapor flows

- Measured flow mostly liquid at start, transitions to mostly vapor after ~90s
- Consistent with visual observations

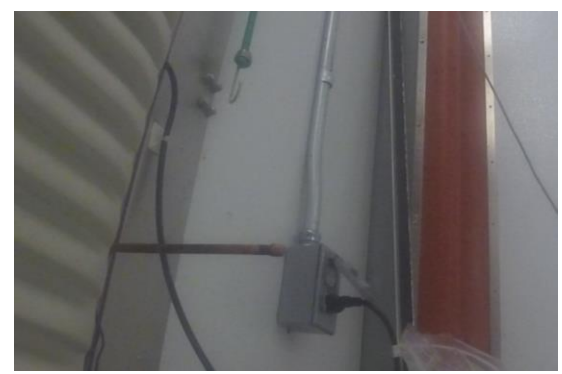




At leak start



At~60s



At~90s

Remaining Project Work — Leak Rate Correlation Development

Planned approach to leak rate correlation:

- Calculate leak flow (or mass flux) for 100% liquid and 100% gas using literature equations for flow-through orifice
- Use measured flow (or mass flux) to infer correction factor
- Correlate correction factor to pressure, temperature, remaining charge, other test parameters as needed
- Include Phase 1 and Phase 2 data

Stakeholder Engagement

- This project in mid-stage (~50% complete)
- Primary stakeholder engagement via regular meetings with AHRTI PMS
  - PMS members provided test systems for project
- Coordination through PMS with standards development/revision bodies
  - Feedback led to revising leak orifice size selection criteria (desire some data for longer release times)
- Phase 1 summary presented at AHRTI Flammable Refrigerants Research and Planning Conference, October 2018
- *Key phase 1 takeaways*:
  - Overall leak rate trends similar for AC systems and display case
  - 90%+ charge released in all tests; exception for unit cooler where shut-off valve limited release to ~5% for low side release tests
  - Negligible oil release with refrigerant; exception is split AC, low side release, largest orifice case (~0.16 kg)

Primary publications:

- ***Experimental Evaluation of Refrigerant Leak Characteristics for Different HVAC&R Equipment Types*, ORNL/TM-2018/1058, March 2019 (Phase 1 project report)**
- **Phase 2 report draft targeted for September 2019**

Thank You

Performing Organization(s)

PI Name and Title

PI Tel and/or Email

REFERENCE SLIDES

Project Budget

Project Budget: $643K in FY18; added $207K in FY19 for Phase 2
Variances: Phase 2 added in mid-FY18; to include tests of split heat pump with duct work impacts and multisplit AC system
Cost to Date: ~57% (~$488K) of project budget expended thru March 2019
Additional Funding: none anticipated

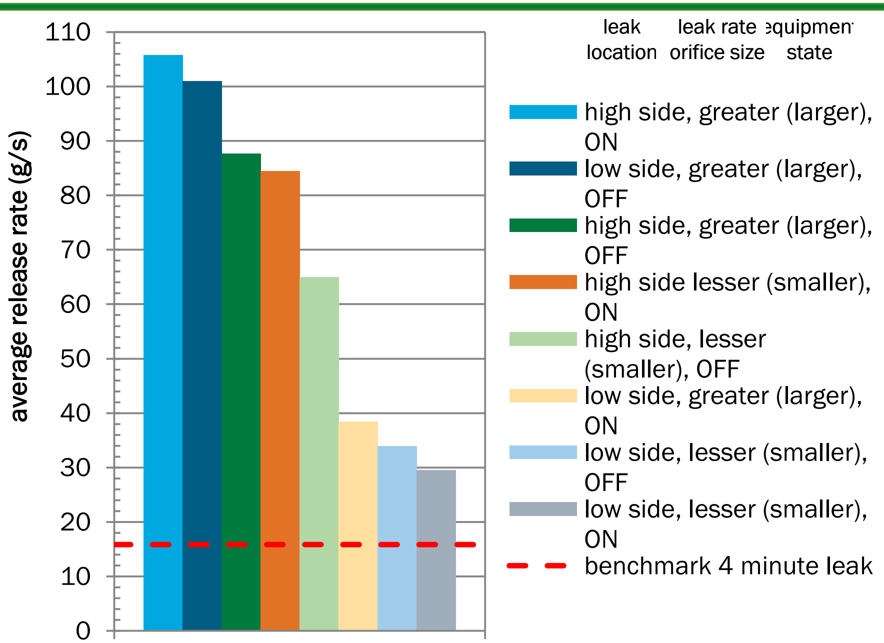
Budget History					
FY 2017-2018 (past)		FY 2019 (current)		FY 2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$643k	$30	$207k	$10	$0	$0

Project Plan and Schedule

- Project initiation date October 2017; planned completion date September 2019
- Key milestones indicated below
- Phase 1 testing program experienced some delays due to equipment malfunctions & repairs required

Project Schedule												
Project Start: October 2017		Completed Work										
Projected End: September 2019		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2017				FY2018				FY2019			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Identify test systems/test plans, Phase 1												
Complete Phase 1 system tests / draft report												
Identify test systems/test plans, Phase 2												
Current/Future Work												
Complete Phase 2 system tests												
Complete leak rate correlation(s) development												
Complete Phase 2 draft report												

Phase 2 proposed orifice selection approach



Split AC results from Phase 1

- "Large" orifice 0.277" (~7 mm)
  - Release rates 6-7 times rate for 4-min benchmark
- "Smaller" orifice 0.162" (~4mm; ~35% flow area)
  - Release rate ~20% lower for high-side leak, unit "on" condition
  - Rate ~70% lower for low-side leak, unit "off" condition
- NOTE: test rates are for first 80% of charge released; 4-min benchmark rate is for 100% charge release.

Orifice selection approach proposal (under discussion with PMS)

- **Start with 1/8" (~3.2 mm) dia. (size selected for the "smaller" orifice for the 5-ton RTU in Phase 1; took ~5 min to release 93% of the total charge (all that would leave) for the low side, compressor off condition).**
- **Pick one of "worst" case conditions above.**
  - high side, unit on condition will require a smaller orifice for 4-min release time than will low side, compressor off condition.
- **Run leak test and record the time required to release the entire charge (or as much as will leave the unit).**
- **Pick smaller orifice (suggest 1 mm diameter, the smallest one used in Phase 1) and rerun the test.**
- **Review the results; did release times bracket 4 minutes? If not, choose 0.5 mm orifice and rerun the test.**
- **Repeat step 5 until 4-min release time is bracketed (expect only 1-2 additional trials should be needed).**
- **Pick orifice diameter between those of last two trial tests and rerun the test; analyze release times for the three tests and define orifice diameter for 4-minute release. Use this diameter for ALL "large orifice" test conditions for both heating and cooling tests; use smallest orifice diameter tested for ALL "smaller" orifice tests.**